A Prediction-Based Algorithm for Tracking Moving Targets in Wireless Sensor Networks to Reduce the Number of Working Nodes

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Abstract: A crucial issue in wireless sensor networks is target tracking which aims to detect and follow the target upon arrival at the area of sensor nodes and this process continues until the target exits this area. Target tracking can be done in several ways including prediction. In this method, to save more energy, only the nodes that can see the target are awake at any moment. These nodes try to predict the next scope of target and awaken the nodes at that scope before reaching the target. A prediction-based target tracking method is presented that tries to awaken a very small number of nodes. Therefore, among the nodes that can track the target, only the two nearest nodes to the target awaken their neighbor nodes, and other nodes are not involved. To evaluate the proposed method, several experiments were conducted and the results were compared with those of similar methods such as Randomized Activation (RA), Naïve Activation (NA) and Distributed Sensor Activation (DSA) [3]. The simulation results show that the proposed method has higher accuracy in target tracking and can reduce energy consumption compared to previous methods to an acceptable level [4, 5].

Keywords: Sensor networks, target, node, sensing range, communication range.

1. Introduction

Wireless sensor networks consist of a large number of nodes with limited capabilities in processing, establishing wireless communication, and detecting one or more physical or chemical phenomena. An important feature of these nodes is limited energy resources, so these networks have a certain life span. In addition, they are more restricted than ad hoc networks in terms of processing and radio communication range. Given the above, the algorithms proposed should be designed efficiently. Moreover, due to these minimum specifications, wireless sensor nodes are low cost, thus enabling the deployment of large numbers of nodes in a network. Wireless sensor networks are primarily used for monitoring large areas containing specific events and tracking moving targets. These applications usually require that a wide environment, which is largely inaccessible by humans, be observed for a long time. Measured changes (physical and chemical phenomena or moving targets) are reported by the sensor to a control center. In some cases, actions are carried out by the control center. Examples of application areas of this network include military environments, natural resources, animal habitats, urban environments, factories, homes, and urban areas. [1]

2. Introducing the DSA algorithm

For target tracking, this algorithm uses the awake or sleeping nodes technique in the entire

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network because of reduced energy consumption. Since the path of moving targets such as humans or animals is unclear, techniques for predicting targets in these cases are somewhat difficult and challenging. However, with the availability of maximum target speed, prediction techniques can be used with maximum efficiency. In this method, the following parameters are used:

R_s: Radius of sensing range

R_c: Radius of communication range

n_{sd}: The number of sensors in the tracking mode that detect the target.

The algorithm uses the binary identification sensing model. This means that the sensor detects the target whenever it enters its sensing scope [6]. A circle with a radius of R_s is assumed as the sensing scope. This model is shown with the following assumption:

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

where $S_i(T)$ is the result of sensing the node s_i for detecting target T, and $d(s_i,T)$ is the distance between the sensor and target T [2].

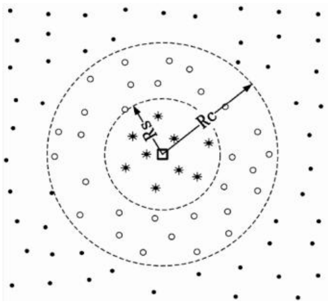

Figure 1: The sensing model and the communication model [2]

The communication model is similar to the sensing model except that it covers a greater scope.

2.1 Locating the centroid

It is assumed that (X_T,Y_T) is the coordinates of target T. In this mode, all the nodes in a circle centered at (X_T,Y_T) and a radius of R_s can detect target T. The approximate coordinates of the target with respect to the coordinates of the working nodes are derived from the following formulas:

$$\bar{X} = \frac{1}{n_{sd}} \sum_{i=1}^{n_{sd}} x_i \quad (2)$$

$$\bar{Y} = \frac{1}{n_{sd}} \sum_{i=1}^{n_{sd}} Y_i \quad (3)$$

where (x_i,y_i) is the coordinates of sensor s_i and $(\bar{x}_i, \bar{y}_i)$ is the estimated coordinates of the target.

It is assumed that all sensors have three modes: communication, sensing, and sleeping. To ensure communication to all sensors, some sensors are required to send or receive data which are called sink sensors. Thus, all sink sensors are in the communication mode except when they detect the target. Ordinary sensors in the network are either in the sensing mode to detect the target or in the sleeping mode to save energy.

Table 1 shows the activity of various components of sensors in different modes.

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Table 1: Activity of different components of sensors in different modes [2]

Mode	Sensing	Communication	Sleeping
CPU	Y	Y	N
Sensing	Y	N	N
Receiving	Y	Y	N
Transmitting	Y	Y	N
Radio-Trigger	N	N	Y
Timer	N	N	Y

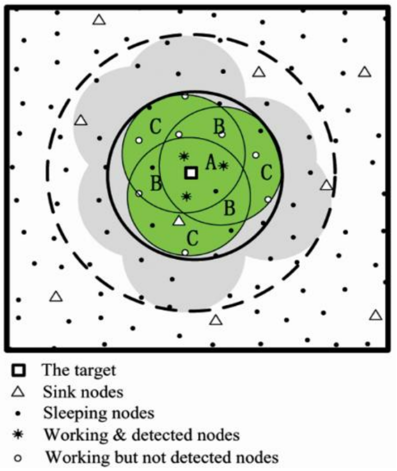

Figure 2: Sensing scopes of nodes [2]

The routine of target tracking can be seen in Figure 2. Asterisk nodes detect the target when it enters their sensing scope and then send a wake-up message to their first-step neighbors (the nodes within their communication radius) which are highlighted in solid green. Nodes in this scope are awake for target detection. Generally, the working scope is shown with solid lines. These nodes also activate sink nodes in their communication radius for sensing (gray circles). As a result, the working scope enlarges to the dotted circle. This procedure is frequently repeated [2]. As is clear, this method awakens nodes in a wide area, so many nodes are activated which leads to the loss of energy of these nodes. Moreover, a large number of these nodes do not have to wake up and have no effects on the tracking process. Therefore, efforts should be made to optimize this algorithm and resolve its problems.

3. The proposed method

This section describes the proposed method for node detection and tracking and tries to present all the necessary details to understand it. To illustrate the proposed method, we first define the problem and then present the appropriate solution to solve it. Here is the problem statement.

3.1 Problem statement

In the target tracking field, what is intended is to track the target once it enters the scope of sensor nodes and not to lose it until departing from the scope. The proposed method is based on prediction, so it tries to predict the target's next place.

In the model that will be discussed next, as shown in Figure 3, the communication range is the scope in which the node's telecommunications equipment can broadcast data, represented by R_c. It is the scope whose distance from the node is less than R_c. The sensing range is the range in which the node can sense environmental factors. The sensing range is represented by R_c. The relationship between these two is as $R_c \geq 2 \times R_s$. The communication range is divided into two types: R_{c1} and R_{c2} where R_{c2} is equal to $2R_{c1}$. To ensure better accuracy, R_{c1} is used. Moreover, the sensing radius (R_s) and communication radius (R_c) are considered identical for all nodes in the network. This algorithm uses the binary detection sensing model, meaning that the sensor detects the target whenever it enters its sensing scope.

Before the target enters the next area, the algorithm must have the ability of earlier predicting this area and activating its nodes. This prediction can have a substantial impact on reducing energy consumption because all nodes are not needed to wake up and wait for the target. In other words, the problem of previous algorithms (many nodes were awakened) is solved, and the number of nodes involved in target tracking will reduce. This reduction in awake and involved nodes has a direct impact on reducing energy consumption of all nodes.

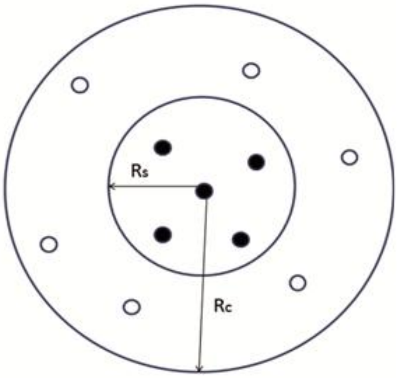

Figure 3: The sensing and communication model

3.2 Overview of the proposed method

In the proposed method, the target placement scope in the next time interval is considered as a circle centered at the current coordinates of the target with a radius proportional to the target's current estimated speed. By determining a certain maximum for the target speed and assuming that the target movement will not change during the decision interval for selecting the next working nodes, it can be shown that (the proof is given below) this scope is placed in the common area made up of the communication domain of the two nearest nodes to the target. Accordingly, an algorithm is proposed that, using the results of this argument, tries to minimize the number of activated nodes for target tracking in the next time interval. Obviously, the reduction of working nodes in tracking, as far as the tracking quality is not impaired, will enhance the network longevity without loss of tracking quality.

To reduce the number of nodes involved in target tracking and ensure the target is detected in the next time interval, as seen in Figure 4, the target is limited within the common communication scope of the two nearest nodes to the target. In other words, with the following conditions and assumptions used, it is predicted that the desired target in the next step will be located in the common communication scope of the two nearest nodes to the target.

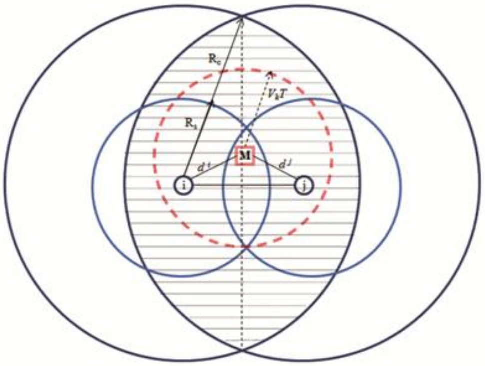

Figure 4: Example of the target placement in the sensor nodes

To illustrate that "by determining a certain maximum for the target speed and assuming that the target movement will not change during the

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decision interval for selecting the next working nodes, the target placement scope in the next time interval is the common area made up of the communication domain of the two nearest nodes to the target," the following theorem is stated:

Theorem 1:

Theorem: According to Figure 4, assume that M is a moving target in the network placed in the coordinates (x_k,y_k) at time k and is moving with a speed of V_k; i, j are the two nearest sensor nodes to M in the network at time k which can sense the target and their distances to M are d^i and d^j, respectively. The sensing and communication radiuses for all sensor nodes in the network are represented by R_S and R_C, respectively and $R_c \geq 2 \times R_s$. Assuming that the target speed does not exceed Rs/T at the time interval [k, k + T] $(V_k \leq R_s/T)$, show the target placement at time T+k (x_{k+T},y_{k+T}) will be in the common area made up of the i and j communication domains (shaded area in Figure 4).

Argument: Given that the maximum target speed in the interval [k, k+T] is considered to be R_s/T, the target at time k+T will be necessarily in a circle centered at (x_k,y_k) with a radius of $(T \times R_s/T)$. Moreover, the target distances to the nodes i and j at time k+T are R_S+d^i and R_s+d^j at maximum.

Since the target is sensible by the nodes i and j at time k, we have: $d^i, d^j \leq R_s$. Therefore, the target distance to the nodes i and j at time k+T is $2R_s$ at maximum. Assuming that $R_c \geq 2 \times R_s$, at time k+T the target will be in the communication radius of both nodes i and j. In other words, at time k+T the target will be in the common space of the domains of the nodes i and j.

3.3 Algorithm description

The proposed algorithm is a distributed one. The mode of each node depends on the neighboring sensor nodes. Ordinary sensor nodes switch between tracking, monitoring, and sleeping modes. The implementation of this method is given in Algorithm 1.

Algorithm 1:

```
Begin
    Switch the working mode of sensor do
    Case sleeping mode
    If timer is up then
        Change to monitoring mode;
    Else if get activation message then
        Change to monitoring mode;
    Else wait;
    Case monitoring mode
        Detecting target;
    If target detected then
        Broadcast "wake" message to one
        hop neighbor;
        Change to target mode;
    Else
        Change to sleeping mode until
        receive "activated" message;
    Case target (tracking) mode
     If the nearest node then
        Broadcast "wake" message to one
        hop neighbor;
        Tracking target;
    Else
        Tracking target;
End
```

At first, when a target enters the sensing scopes, the nodes that detect it switch to the tracking mode and remain in this mode until the target exits their sensing scope. When the target exits the sensing scopes of nodes, the tracking nodes return to sleeping mode. But among the nodes in the tracking mode, only the two nodes in the last time interval with minimum distance to the target can send a wake-up message to their first-step neighbors. This is why it is predicted that the target in the next step will be in the common communication scope of its two nearest nodes (based on the assumptions and the argument mentioned in the previous section). The nodes that see the target immediately communicate by sending packets to each other. In the packets sent by these nodes, there is a field called distance to target which is infinite by default. When a node sees the target, it enters its distance to the target in this field, and the nodes (by exchanging messages) find the two nearest nodes to the target. As stated before, only these nodes can awaken first-step neighboring nodes.

There is also a field called ID. Each node is randomly assigned a number for this field and the minimum number among awakened nodes is selected as the agent node.

After receiving a wake-up message, the first-step neighboring nodes switch to the monitoring mode and get ready to sense the target. When these nodes see the target, they inform the agent node. The agent node, after receiving two messages from two different nodes indicating that the target is visible, declares to the two nearest nodes that it awakened in the previous step that the target is visible. Moreover, among themselves, they find the two nearest nodes to the target.

If these nodes do not detect the target and no working node exists at the moment, they switch to the sleeping mode to avoid waste of energy. This way, one can minimize the time nodes are in the monitoring mode to reduce total energy consumption in the network. Moreover, the two nearest nodes to the target in the previous step that awakened the first-step neighbors wait to receive a message from these nodes indicating that the target is visible. If this message is not received after a certain time (time out), they notice that the target is missing. In this case, a special algorithm is used which is presented next. This routine is repeated at each step.

3.4 Example scenario

As it is observed, the nodes that participate in tracking at time t are shown in Figure 5. The nodes S1, S2, and S3 have observed the target but just the two nearest nodes to the target are allowed to awaken other nodes. It is assumed that after the exchange of messages between the three nodes, the nodes S1 and S2 have minimum distance to the target and it is expected that the target, in its next move, be placed in the common communication scope of these two nodes (shaded in Figure 5), so they can activate their first-step neighbors.

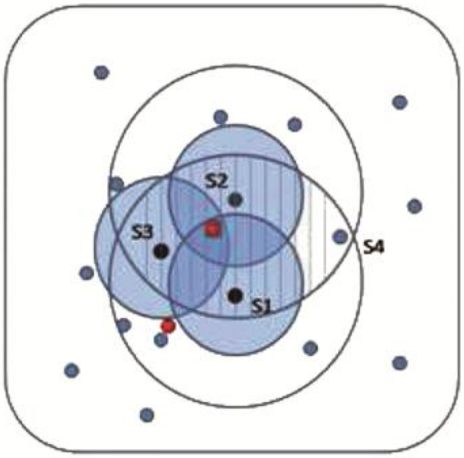

Figure 5: Target position between the nodes S1, S2, and S3

At time t+1, the target moves and exits the monitoring scope of S1 and is located in the common communication scope of the two nodes S1 and S2, as predicted (Figure 6).

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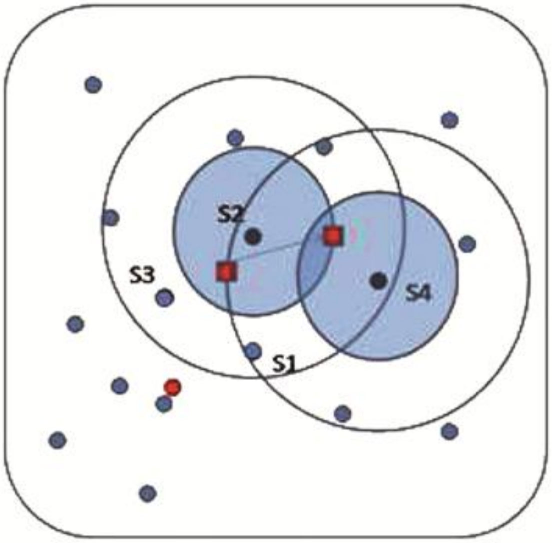

Figure 6: Target position between the nodes S2, S4, and S8

In this mode, the nodes activated by the nodes S1 and S2 wait to see the target. Once they see it, the two nearest nodes are designated (the nodes S2 and S4 see the target, while they are the two nearest nodes to the target) and inform the nodes S1 and S2, by the agent node, that the target is visible. This procedure continues until the target leaves the desired scope.

3.5 Special case (missing target)

Now a special case occurs for which a remedy must be devised. Here the question is that if only node p is available around i and j (as shown in Figure 7), the proposed algorithm does not allow it to be activated. Although if the network is dense, it is a very low probability event, we must devise a remedy for it to have a comprehensive algorithm.

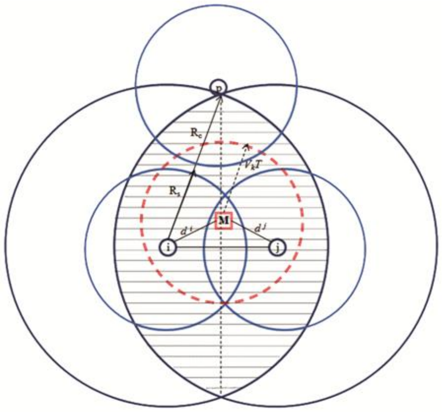

Figure 7: Missing target

This problem can be considered to be the target being lost. In the general case of the proposed algorithm, if the target is missing or such a situation occurs, the target must be found at minimum cost. If the target is placed in a situation that the two nearest nodes to the target are not present to activate other nodes and continue the tracking procedure, it is attempted to find the target with the help of the two nearest nodes to the target in the previous step. The algorithm is presented next.

In this method, the two nearest nodes to the target at the penultimate step try to awaken other nodes to find the target. Since the target is unknown, the wake-up message is broadcasted on the network. But since the target speed is limited according to Theorem 1, one can awaken nodes that may be near the target, in a certain communication domain, and the entire node is not required to switch from monitoring to sleeping mode for tracking. Here it is suggested that the two nearest nodes to the target in the previous step with a communication radius of R_{c2} (twice the radius R_{c1}) switch other nodes to the monitoring mode. As stated in the algorithm description, the two nearest nodes to the target, after wake-up, wait for a message from the nodes awakened by them. If this message is not received, the target is missing. For example, in

Figure 7, the two nodes i and j must awaken their first-step neighbors, but since there is no such node, naturally they receive no message conveying that the target is found. Therefore, they use the communication radius of R_{c2} to awaken other nodes (node P).

```
Begin
    Node i: the nearest distance detected node
    to  the target
    Node j: another nearest distance detected
    node to the target
    For each node k which is node i neighbor
        Change node k to target mode
        For each node g which is node k
            neighbor
                Change node g to target
                 mode
        End
    End
    For each node k which is node j neighbor
        Change node k to target mode
        For each node g which is node k
            neighbor
                Change node g to target mode
        End
    End
End
```

4. Simulation

MATLAB was used for simulation, the network parameters were initialized according to Table 2 and simulation was implemented. The initial energy of all nodes was assumed to be identical.

Table 2: Simulation conditions

Initial energy of nodes	5 J
Sensing radius (Rs)	30 m
Communication radius (Rc)	60m
Network dimensions	500 x 500 m
Number of nodes	250
Node distribution strategy	Random
Energy required to amplify transition (Eamp)	0.0013 * 0. 000000000001 j
Energy required to transmit and receive (Eelect)	50 * 0.000000001j
Length of control packets	12 bits
Energy consumption in sleeping mode	0.00027 J
Energy consumption in sensing mode	0.012 J
Energy consumption in communication mode	0.0378 J
Target movement model	Random Waypoint movement model

Energy model:

Energy required to send k packets in distance d is obtained as follows:

$$E_T(k,d) = Eelect \times k + Eamp \times k \times d^2 \quad [3] \quad (4)$$

Energy required to receive a packet is obtained as follows:

$$E_R(k) = Eelect \times k \quad [3] \quad (5)$$

Given the above parameters, simulation is run. Figure 8 is an example of simulation. In this figure, the target path is represented by dotted lines and the target stop location by a green (star-like) icon. Sensor nodes in the sleeping mode are represented by blue (hollow) circles and the nodes that the target is located in their sensing area are represented by the red "x" symbol, and the nodes that switch to the monitoring mode after wake-up are represented by the symbol "+". The target is detected and tracked as soon as it enters the test area and is followed until it exits the area. To achieve reliable results, the proposed plan was executed 30 times. The average results are presented. Each simulation starts upon arrival of the target to the desired area and ends when it exits the area.

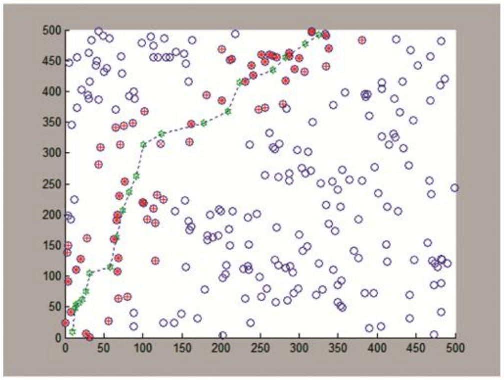

Figure 8: Target movement in a random distribution of nodes

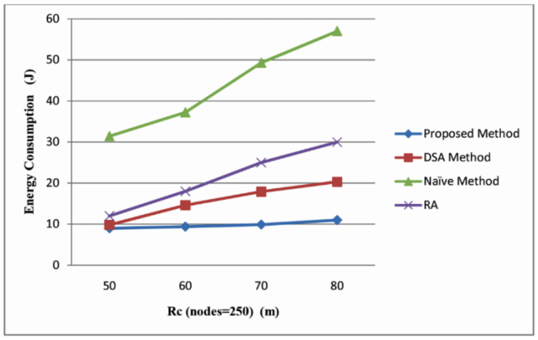

Figure 9: Relationship between energy consumption in the four DSA, Naive, RA, and the proposed method

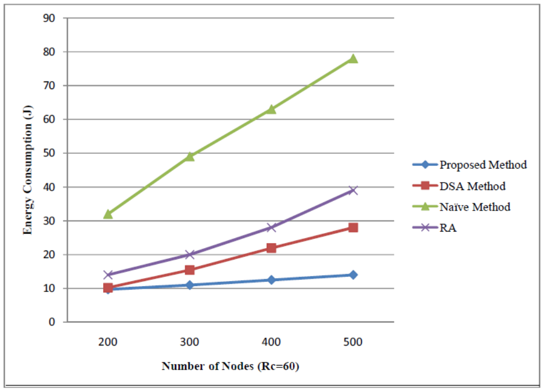

Figure 10: Impact of the number of nodes on energy consumption

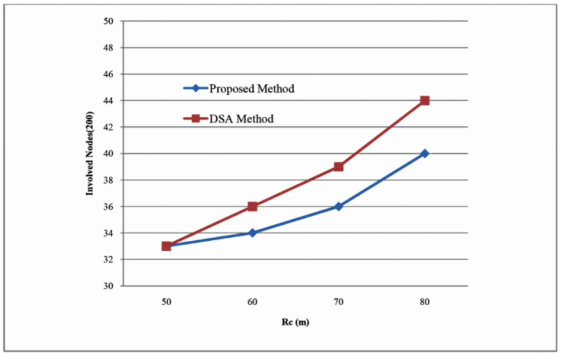

Figure 11: The number of nodes involved in target tracking in the proposed method and DSA

5. Conclusion

This paper proposed a prediction method which switches a very small number of nodes to working mode for target tracking, and switches other nodes to sleeping mode. Energy consumption is reduced by reducing the nodes involved in target tracking and activating a few nodes essential for target tracking. According to the simulation results, the proposed method reduced energy consumption to an acceptable level compared to previous methods while increasing accuracy in target tracking.

Experiments proved that the proposed algorithm is far better than similar algorithms in terms of different criteria including energy consumption in different communication domains, impact of the number of nodes on the energy consumption of nodes, the number of nodes involved in tracking in terms of communication domain and missing target, so the proposed method is more effective and superior.

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