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Prediction-based, Node Clustering and Node Scheduling for Multi Active Target Tracking in Chain-type Wireless Sensor Networks

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Abstract: Chain-type wireless sensor network is a type of Wireless Sensor Network (WSN). Target tracking is an important application in this network. This paper works on node clustering, node scheduling, predicting location of targets and target tracking in Chain-type WSNs. Node clustering algorithm is proposed for better management of data handling and less energy consumption. Node scheduling is proposed for increasing the life time of network. Prediction algorithm is proposed for estimating the next location of target in order to save energy consumption by reducing the number of packet transmissions. Proposed target tracking algorithm solves data association problem for active targets in Chain-type WSNs. Simulation results show that targets can be traced accurately and energy efficiently.
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1. Introduction

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

There are two tasks for monitoring chain-type environment such as roads, railways, mines, rivers and bridges: one is the environmental information monitoring, for example gas concentration of mine monitoring, water level of the river or the lake monitoring, and deformation of bridge monitoring; the other is locating moving objects in the monitoring region, for example locating vehicles, shipping, and miners. Since a chain-type environment is narrow and long, sensor nodes are only placed linearly, we call this kind of network chain-type wireless sensor network.

Locating or tracking a moving target is an essential task for WSNs in many practical applications, such as robot navigation, security surveillance and battlefield awareness. Now, there are three kinds of tracking strategies: perfect tracking strategy, random tracking strategy, and collaboration tracking strategy [1].

(1) Perfect tracking strategy is that all nodes track a moving target. Although this strategy has a high tracking accuracy it may cause the network consume much energy and increase the burden of data integration and elimination of redundant information.

(2) Random tracking strategy is that each tracking node participates in tracking a moving target only with probability. Obviously, this strategy decreases the energy consumption of the network because of the limiting number of tracking nodes, and so the tracking accuracy cannot be ensured.

(3) Collaboration tracking strategy is that only selected tracking nodes participate in tracking a moving target with the tracking algorithm. This strategy both decreases the network energy consuming and ensures the tracking accuracy by the mutual cooperation between tracking nodes.

We need to predict the location of a moving target by prediction algorithm in WSNs in order to track a target real-time and accurately, which is called a trajectory prediction problem. The trajectory prediction of a moving target needs to make the prediction value of a moving target close to the actual value. A target tracking problem is non-linear, which can be solved by the sequential estimation methods such as Bayesian estimation, Kalman filtering, and Particle filtering.

Considering scalability of a WSN leads to clustering. 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 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.

Node scheduling means setting a sleep/active schedule for nodes. In active mode, node can sense and communicate. However in sleep mode, node is inactive for saving its energy.

The rest of this paper is as follows: in section 2 we have an overview of some existing algorithms for target tracking, in section 3 we present Chain-type WSN, in section 4 we explain proposed algorithms, in section 5 we present the simulation results of the proposed algorithms and evaluate their performance, and in the last section we conclude the paper.

2. RELATED WORK

According to [12], there are three main approaches for target tracking in WSN: tree-based, cluster-based and prediction-based algorithms.

Tree-based methods organize the network into a hierarchy tree. Example of tree-based methods includes STUN (Scalable Tracking Using Networked Sensors) [14], DCTC (Dynamic Convoy Tree-based Collaboration) [15], OCO (Optimized Communication & Organization) [16], and LFFT (Large Frequency First Tree) [17]. 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 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 [17] 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 nodes. Example of cluster-based methods is presented in [18]. In this paper, authors proposed a dynamic clustering algorithm for acoustic target tracking in WSN. In this method, in each interval time, a CH, that is nearest to target, is selected as active CH. When an active CH was selected, it 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.

Prediction-based methods are built upon the tree-based and the cluster-based methods, with added prediction models. These algorithms with a prediction mechanism predict the next location of target and with attention to estimated location, They only select dome nodes that are near to this location for tracking and other nodes remain in sleep mode for energy saving, Example of prediction-based algorithm are DPR (Dual Prediction-based Reporting) [19] and linear prediction [7]. 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 is sent to the sink and therefore the number of packets transmitted decrease. In [7] the authors used a liner method to estimate the next location of a target. In [2] the author used RBF neural networks to predict the next location of a target in chain-type WSN.

3. CHAIN-TYPE WSN

A tracking prediction model for chain-type wireless sensor networks is shown in Fig.1.

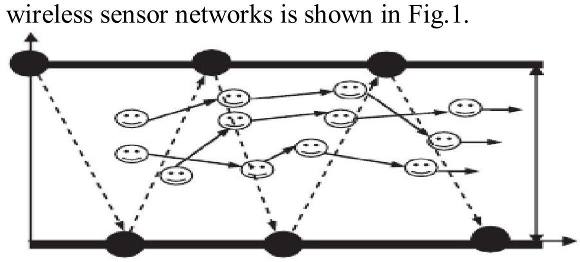

Figure 1. Chain-type tracking prediction model

In Fig.1, Two black thick solid lines denote the boundaries of the chain-type region: black solid circle denoted the tracking node; tracking nodes are placed on the boundaries of the chain-type region according to the deployment policy. The data transportation of the network is chain, and the dotted line denotes the direction of data flow: face-like image denotes the target node; the solid line denotes the direction of moving target node.

4. Proposed Algorithms

In this section, proposed algorithms are explained in detail.

4.1 Prediction Algorithm

Prediction-based algorithms in target tracking are algorithms that predict the next location of the target. Then with attention to predicted location, specific nodes are activated 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 by using current and previous location of the target. Target's speed can be calculated 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:

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

If this location is placed in the current cluster, active CH selects 2 sensor nodes for target tracking in the next time interval. Otherwise, active CH selects nearest CH to that location as the 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 our algorithm the next location of target is calculated at both CH and sink. When CH calculates the location of target, CH compares it with the predicted location, if the difference is less than a threshold (TH), no packet is transmitted to the sink and therefore the number of packet transmitted decrease, which results in increasing the network life time.

4.2 Node Scheduling Algorithm

In the proposed algorithm, all CHs have the same active/sleep schedule. They are in active mode for 1ms and are in sleep mode for 999ms. This schedule is repeated periodically until the life time of network is expired. In active period, CH checks the surrounding environment for target detection or any packet from other CHs. In sleep mode, CH's transmitter is off for energy saving.

4.3 Clustering Algorithm

In order to manage network better and decrease energy consumption, the networks is divided into several sections. In each section only the CH is active and other member nodes are in sleep mode.

We supposed that the length of network area is L, width is W, sensing range is r, and node communication range is R, the length of each cluster (each section) can be calculated as:

$$(L1'^2 + W^2) \le r^2 \qquad (4)$$

$L1'$ is the distance between the CH and the target.

Also for establishing communication between 2 sections, the below equation should be satisfied:

$$((2L1'')^2 + W^2) \le R^2 \qquad (5)$$

$2L1''$ is the maximum horizontal distance between two CHs.

Finally, the length of each section (L1) is calculated as:

$$L1 = 0.75\text{minimum}(L1', L1'') \qquad (6)$$

The number of section is:

Number of Sections (NS) =L/L1 (7)

So the total nodes (N) in 2 rows in NS section are randomly distributed. In each section, only the CH is active periodically. The procedure of choosing CH is based on energy of the node; every node that has the highest energy is selected as CH. After consuming TR=%5 of CH energy, the process of CH selection is repeated. When several nodes have the same energy, every node picks up a random number between 0-255 and each node that has the highest number is selected as CH. If several nodes have the same big number, the process is repeated.

4.4 Single Target Tracking Algorithm

When a target enters the network area, A CH detects it and the following steps are done:

1-The CH sends a packet to the sink, indicating that a target is detected.

2-The CH sends a message to its members.

3-Members send their energy and distance from the target to the CH.

4-The CH with the following index selects 2 nodes to track the target:

$$ED_i = \frac{ResidualEnergy_i}{Distance^2_i} \qquad (8)$$

5-The 2 selected nodes send their coordinator and their distance from the target to the CH.

6-The CH calculates the coordination of the target as:

$$(x_i - x_t)^2 + (y_i - y_t)^2 = d_i^2 \qquad (9)$$

(i=1, 2, 3)

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

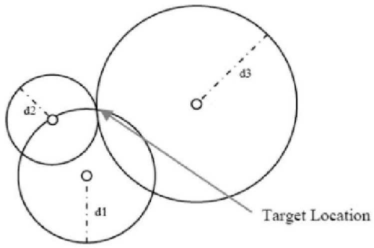

Figure 2. Trilateration Localization Algorithm

7-The CH executes the prediction algorithm and estimates the next location of target.
8-CH compares actual location of target with the predicted location, if the difference is less than a threshold (TH), no packet is transmitted to the sink.
9-Another CH is activated based on the next location of target.

4.5 Multi Target Tracking Algorithm

When there are multi target in network area, we face data association problem. Considering that all targets are active the problem can be solved as:

There is a node on each target. Every installed node picks up a random number between 0-1024 and sends it periodically. A CH receives this ID and encapsulates it in its own packet and sends to the sink. When a node detects more than one target, the node selects the nearest target to track.

5. SIMULATION RESULTS

In this section, using computer simulation, we evaluate performance of proposed algorithms. Our algorithms are simulated in CASTALIA 3.2, which is dedicated for WSN and is a framework of OMNET++ 4.2.2 software.

For simulation, two programs were written. One for target appearing and the other one for target tracking. Parameters are set in table 1:

Table 1. Parameters of network

Length of network (L)	120 M
Width of network (W)	10 M
Sensing range (r)	20 M
Communication range (R)	40 M
Node initial energy	0.5 J
Velocity of targets	0-12 M/S
Simulation time	60 Minutes
Transmission band	2.4 GHz
Communication rate	250 Kbps
The sink coordination	(60,10)

For performance evaluation of the algorithms, two indexes are used:

1-Average Number of Dead Nodes of the Network

2- Average Energy Consumption (AEC) of the Nodes

The energy model used in our simulation is the same as the one used in [7]:

$$E_{TX}(k,d) = E_{elec} + E_{amp} * d^{\alpha} \quad (10)$$

$$E_{RX}(k) = E_{elec} \quad (11)$$

$$\alpha = 2$$

$$E_{elec} = 50nJ / bit$$

$$E_{amp} = 10pJ / bit / m^2$$

In this model, the energy consumption to transmit a packet to a distance d is (E_{Tx}) and energy consumption to receive a packet is (E_{Rx}).

In Fig. 3, the effect of increasing number of nodes versus the Average Number of Dead Nodes of the Network is shown. We can see when the number of nodes increases, since the work load distributes between more nodes, the average number of dead nodes decreases.

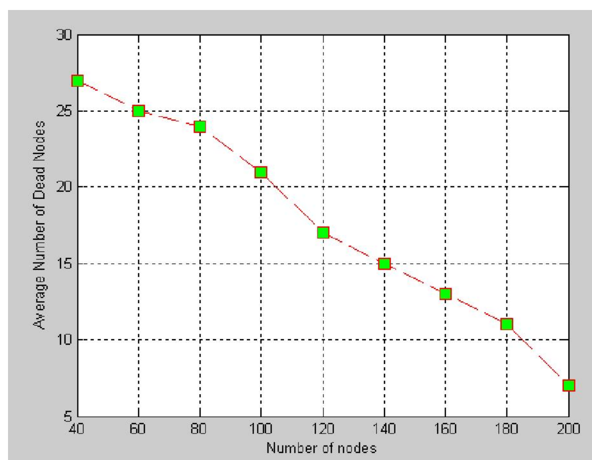

Figure 3. Number of nodes vs. Average Number of Dead Nodes

In Fig. 4, Average Energy Consumption (AEC) of Nodes is shown during simulation. We can see by passing the time, since nodes consume energy, AEC increases.

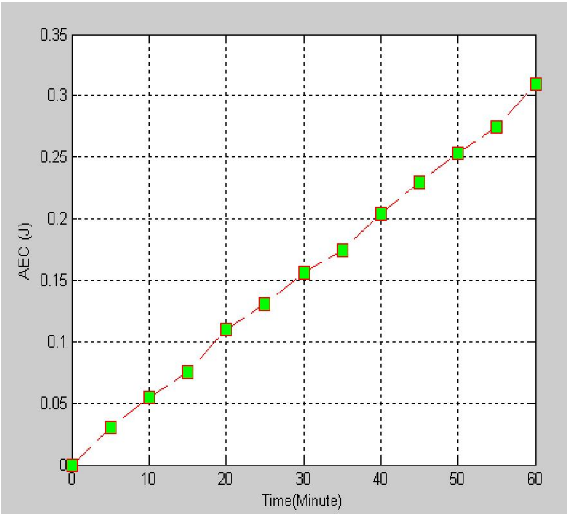

Figure 4. Average energy consumption (AEC) of nodes

In Fig. 5, the total number of nodes is set to 120 and Average Number of Dead Nodes is shown for the following different TR:

TR=%5, %10, and % 1.

We can see that when TR is low, since clustering process occurs more often, energy consumption increases and results in increasing the average Number of Dead Nodes. We can also see when the TR is high clustering process occurs less often, which leads clustering to static clustering that eventually leads to increasing the Average Number of Dead Nodes.

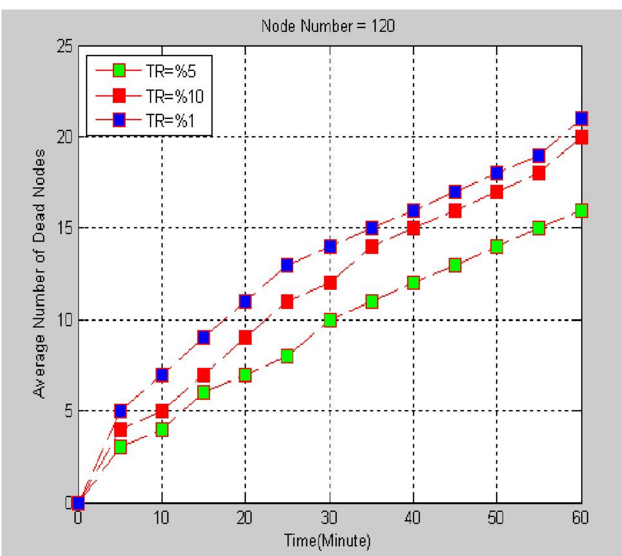

Figure 5. Average Number of Dead Nodes as a function of time for different TRs

In Fig. 6, the total number of nodes is set to 120 and Average Number of Dead Nodes is shown for different TH:

TH=0.5, 1, and 2 Meter.

We can see when TH is low, since more packets are sent to the sink, more nodes are dead and when TR is high, since fewer packets are sent to the sink, fewer nodes are dead. However, When TR is too high tracking error is high too.

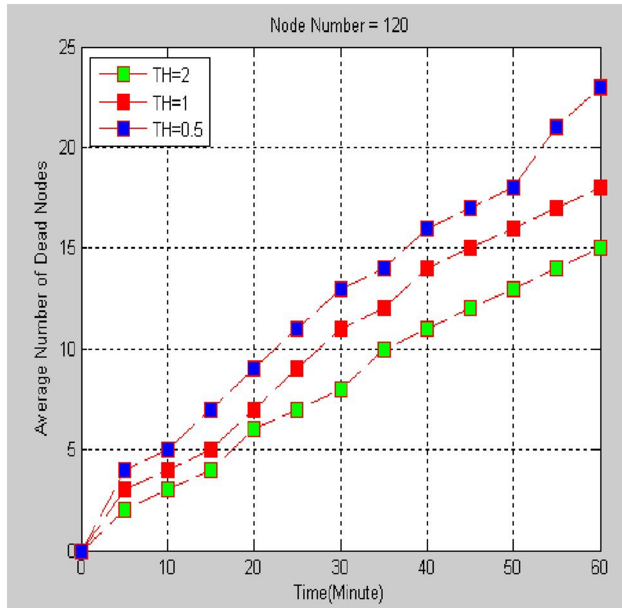

Figure 6. Average number of Dead Nodes as a function of time for different THs

6. CONCLUSION

In this paper, multi active target tracking in chain-type WSN was investigated. We proposed node clustering, node scheduling, prediction and target tracking algorithms. Simulation results showed that multi target could be tracked accurately and energy efficiently. One of the practical applications could be positioning and tracking robots in mines. Tracking of passive targets would be a challenge for the future works.

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