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Target Tracking Based on Virtual Grid in Wireless Sensor Networks

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Abstract
One of the most important and typical applications of Wireless Sensor Networks (WSNs) is target tracking. Although target tracking can provide benefits for large-scale WSNs and organize them into clusters, tracking a moving target in cluster-based WSNs suffers from a boundary problem. The main goal of this paper is to introduce an efficient and novel mobility management protocol namely Target Tracking Based on Virtual Grid (TTBVG), which integrates on-demand dynamic clustering into a cluster-based WSN for target tracking. This protocol converts on-demand dynamic clusters to scalable cluster-based WSNs using boundary nodes and facilitates sensors' collaboration around clusters. In this manner, each sensor node has the probability of becoming a cluster head and apperceives the trade-off between energy consumption and local sensor collaboration in cluster-based sensor networks. The simulation results of this work demonstrate the efficiency of the proposed protocol in both the one-hop and multi-hop cluster-based sensor networks.

Keywords: *Target Tracking, Virtual Grid, Clustering, Wireless sensor networks, Dynamic Clustering.*

1. Introduction

One of the new low-cost and saving-energy network paradigms that can create applications for monitoring and controlling is Wireless Sensor Networks (WSNs). Target tracking is considered as an important element in WSNs and many practical applications including battlefield surveillance, patient monitoring devices, disaster response, and emergency rescue [1]. With target tracking, a moving target like a person or a vehicle can be tracked with sensing capability of sensors, and the information about the position and location of that moving target can be studied in each time instance [2]; it also benefits from local collaboration and routing [3, 4]. Although target tracking can provide benefits for large-scale WSNs and organize them into clusters, tracking a moving target in cluster-based WSNs suffers from a boundary problem. Recently, the cluster structure has been used to resolve the boundary problems [5,6]. Generally, the nodes that are surrounded by the target cooperate with each other to estimate the place of the target [7–9] but in a dynamic clustering approach, when the target travels in a region wake up a group of nodes used to construct a cluster of local collaborations. In other words, clusters are constituted dynamically as the target moves. It is an efficient way for local sensor collaboration since the clusters formed at each time instant change dynamically [10]. However, the dynamic clustering process has multi-problems, repeating as the target moves, is energy costly, and dynamic clustering does not consider how to efficiently transfer data to the sink [11]. While the target tracking uses the static cluster for the network scalability and energy efficiency, "static cluster" does not mean unchanging of the cluster during the network's entire lifetime; it means unchanging for a relatively long time period compared to a temporally formed dynamic cluster until the next round of clustering process starts[12–15]. In this manner, as shown in the Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol [16], each sensor node has the probability of becoming a cluster head so as to balance the energy load. LEACH [17] is the first typical clustering protocol designed for WSNs. Since it is the first mature

algorithm for cluster formation; LEACH becomes a baseline for successors.
A predictive real mechanism in target tracking is used to inform the cluster heads about the approaching target, and then the corresponding cluster head wakes up a number of appropriate nodes exactly before the arrival of the target. One static cluster can be saved and handed to another without costly dynamic clustering processes. Besides it can provide a scalable structure that coordinates and manages the networks. In large-scale sensor networks, static cluster-based approaches are used more suitably for target tracking. However, when the target moves across or along the boundaries of clusters, the static cluster membership prevents sensors of different clusters to collaborate and share information with each other, boundary problem.
Since the boundary problem can lead to increase the tracking uncertainty or even the scat of the target, a new protocol is necessary to solve the boundary problem and apperceive the trade-off between the energy consumption and the local sensor collaboration in cluster-based sensor networks [18]. In order to solve this problem in cluster-based WSNs, a new mobility management protocol based on virtual grid is suggested, which converts the on-demand dynamic clusters to the scalable cluster-based WSNs.
This paper is organized as what follows. Related works are given in Section 2 that includes a detailed survey of the related research works. The proposed protocol is explained in Section 3 that includes the simulation, and its results are presented in Section 4. Finally, conclusions and future works are presented in Section 5.

2. Related works

There are some important factors such as energy consumption, response time, life time, and lack of energy that are discussed throughout this paper. Energy consumption refers to the amount of energy or power by an individual or organization or to the process or system of such consumption. Response time is the time a system or functional unit takes to react to a given input. The lifetime of a network is defined as the operational time of the network during which it is able to perform the dedicated task(s). In order to clarify the specified factors, in the first part of this paper, some background information is presented.

2.1. Distributed predictive tracking

Distributed Predictive Tracking (DPT) is available in WSN [19]. There are three types of nodes in this protocol: boundary node, typical node, and cluster-head node.
There is no limit to use the clustering protocol but we should have changed some of them. In DPT, two previous locations are used to guess the next target places. After creating the clusters, DPT is executed. Cluster-head can use Target Descriptor (TD) to identify targets and to provide their location information. There is some useful information in each TD such as the target ID, the current location of the target, and the next predicted location of the target. Cluster-heads based on all sensor information are available in their database, start searching, and select the tried sensors. If the target speed or direction changes suddenly, another failure scenario can happen.

2.2. Exponential predictive tracking

Exponential Distributed Predictive Tracking (EDPT) is another tracking protocol in WSN [20]. In this protocol, in order to reduce the energy consumption and response time, an improved predictive algorithm is used that is called Exponential Smoothing Predictive Algorithm (ESPA) [21]. ESPA uses five previous points in the target path to find the next place of the target. If the target is located out of range, recovery will be at work, just like the DPT protocol.

2.3. Virtual grid

One of the most important challenges in WSNs is the lack of energy. Using the virtual grid on networks is an efficient solution to reduce energy consumption [22]. One node that is located in every cell of each type of virtual grid is in the active mode, and the others are in the passive mode, which is depicted in figure 1. As a result, life time increases and energy is stored by the network. Two types of neighborhoods have been defined for these cells. In the first type, each cell can communicate with the horizontal and vertical adjacent cells. In the second type, instead of the horizontal and vertical adjacent cells, each cell can communicate with the diagonal cells as well. Most of the protocols in the WSN context have been used as grids with square cells but there are other types of girds such as grids with triangle cells and grids with polygon cells.

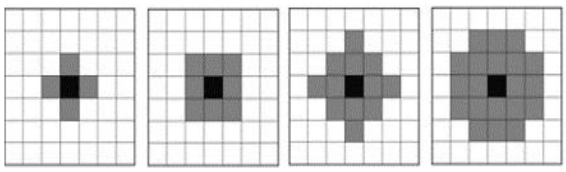

Figure 1. Virtual grid with different types of cells.

Target tracking in WSNs has received a considerable attention in the recent years from various angles, and a lot of protocols have been proposed. Zhao et al. [23] have introduced the collaboration mechanism for target tracking via information-driven dynamic sensors. Brooks et al. [24] have presented a distributed entity-tracking framework for sensor networks. Chen et al. [25] have used distributed sensor scheduling algorithms in networks with binary sensor and acoustic sensor networks, respectively. Wang et al. [26] have proposed a novel localization algorithm for target tracking. VigilNet[27, 28] has designed and implemented an energy-efficient and real-time integrated system for target tracking. Cheng et al. [29] have used distributed Time Division Multiple Access (TDMA) for target tracking. Chen et al. [30], in another research work; have handled a secure localization scheme to defend against some typical attacks.

In order to balance energy consumption and sensor collaboration, a series of dynamic clustering protocols have been applied for target tracking in WSNs [31, 32]. Yang et al. [6] have used an Adaptive Dynamic Cluster-Based Tracking (ADCT) protocol, which selects cluster heads dynamically and wakes up nodes to construct clusters with the aid of a prediction algorithm as the target moves in the network. Zhang and Cao [7] have introduced the Dynamic Convoy Tree-Based Collaboration (DCTC) method to detect and track the mobile target. Ji et al. [8] have represented a dynamic cluster-based structure for object detection and tracking since the convoy tree maybe assumed as a cluster in dynamic configuration by adding and pruning some nodes. Jinet[9] has also proposed a dynamic clustering mechanism for target tracking in WSNs and balancing the missing rate and energy consumption. Medeiros et al. [12] have presented a dynamic clustering algorithm for target tracking in wireless camera Networks. Chen et al. [5], in another work, have introduced a decentralized dynamic clustering protocol based on static sensors.

Several protocols for target tracking are based upon the static cluster structure [13–14]. Heinzelman et al. [16] have converted sensor nodes into clusters using LEACH as a suitable clustering protocol, and Younis et al. [33] have converted it using Hybrid, Energy-Efficient, and Distributed Clustering (HEED). Based on the cluster structure, a Distributed Predictive Tracking (DPT) protocol has been designed by Yang and Sikdar [13], which predicts the next place of the target and notices the cluster head regarding the approaching target. A Hierarchical Prediction Strategy (HPS) for target tracking and implementation of a real target tracking system has been proposed by Wang et al. [14], which depends on the cluster structure.

Cluster-based target tracking protocols take the advantages of underlying the cluster structure in comparison with the dynamic clustering protocols, which are especially suitable for target tracking in large-scale networks. Mobayen et al. [34] have proposed a novel recursive singularity free FTSM (Fast Terminal Sliding Mode) strategy for the finite time tracking control of non-homonymic systems. The results have been stimulated on a wheeled mobile robot and an under-actuated surface vessel, which are two benchmark examples of extended chained-form non-homonymic systems. Mobayen [35], in another work, has presented a new recursive terminal sliding mode strategy for tracking control of disturbed chained-form non-homonymic systems. The simulation results showed the efficiency of this method in the presence of external disturbances. In another work, Mobayen [36] has considered the composite non-linear feedback method for robust tracking control of uncertain linear systems with time-varying delays and disturbances. The experimental results were presented to illustrate the effectiveness of the proposed technique.

3. Proposed protocol

We used the virtual grid with rectangular cells in the proposed protocol (shown in Figure 2) because any cluster could be placed in each cell of the grid.

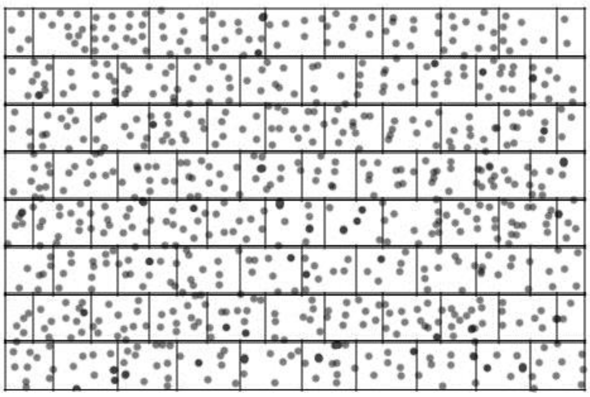

Figure 2. Virtual grid with rectangular cells in proposed protocol.

In target tracking applications in WSNs, for choosing a cluster, the nodes should be equipped with GPS or benefit from a positioning algorithm. The sensor nodes have both the short and long sensing ranges. Normally, a node is activated in short beam, and if the cluster head requests, it will switch to a high beam.

In addition, it is assumed that the nodes are distributed densely in the area of interest. Sink, which is a special node where data is collected, to be able to do its job, should know the width and length of the monitored area. There are two methods for this purpose. The first method is easier and more energy efficient but less flexible. The second one is more flexible but more complex and energy consuming. We chose the latter approach because in this way, at the starting point of grid, the nodes send a Hello message to sink. The sink node collects messages and the length and width of the grid using the flowchart in figure 3.

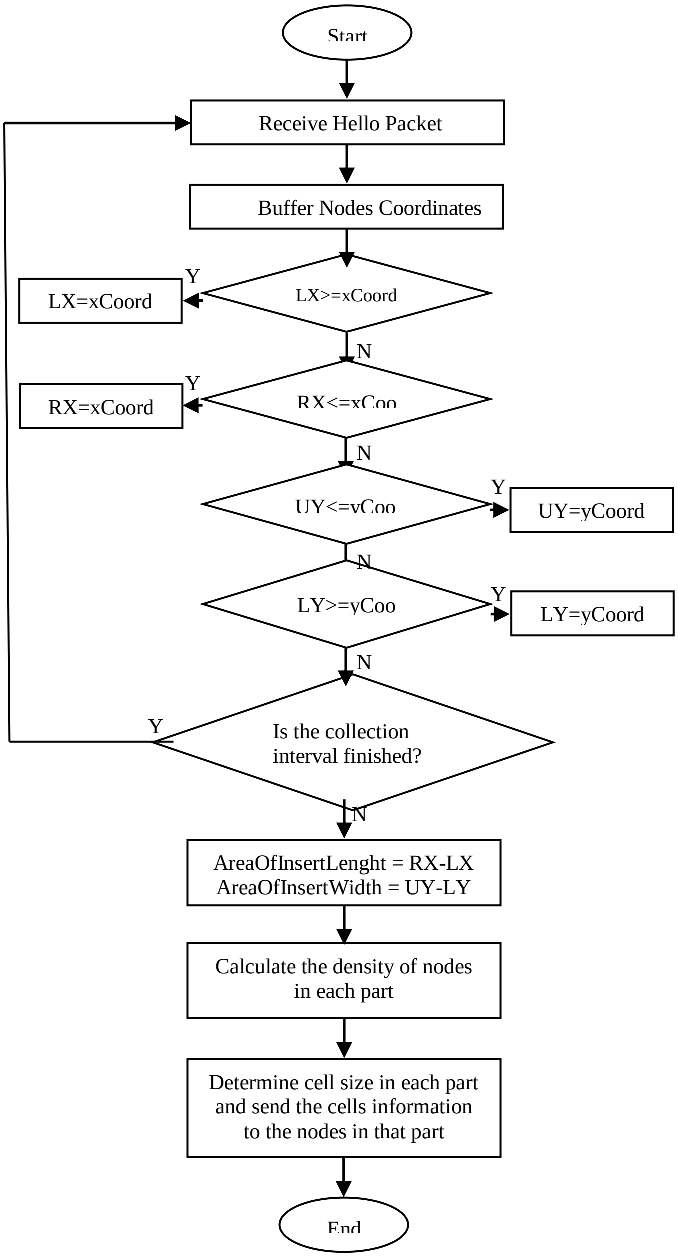

Figure 3. Calculation of length and width of area of interest and cells using sink node.

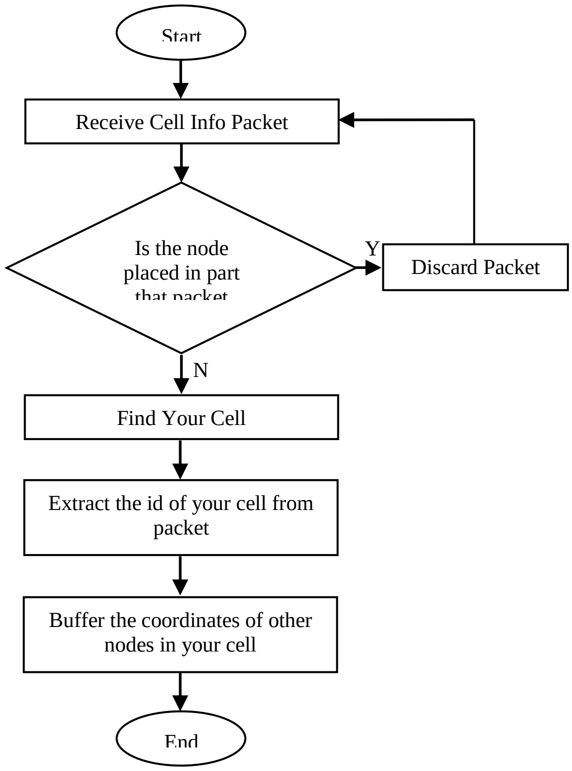

Figure 4. Finding cell and other nodes in cell.

Table 1. Simulation condition.

Parameters	Scenarios Details		
Scenery Size	100×100	100×100	100×100
Antenna	Omni Directional	Omni Directional	Omni Directional
Time Simulation	1500	1500	1500
Sink Number	1	1	1
Common Node Number	200	200	200
Common Node Location	Random	Random	Random
Initial Energy of Common Node	100 Joule	100 Joule	100 Joule
Target speed	2m/s	1.5m/s	1m/s

The nodes identify their cell boundary by analysing information included in the Cell Info packet. The nodes send a Hello message, which contains their coordinates to other nodes in their cell. Then a node is elected as the cluster head based on the identity or its location with respect to the center of cell. The cluster-head node determines the border and non-border nodes. The non-border nodes are scheduled by the cluster head to sleep and wake up. The sensor unit of the non-border nodes is turned off, and it will be turned on by the cluster head demand but their communication unit is turned on if they are in the wake-up mode, otherwise it is turned off.

Tracking of the target starts when the monitored area border nodes detect its effect and report to the cluster head by the Target Entrance name. The cluster head will send a Name Request for assigning an identity number to the target by the sink node if required. Then three sensor nodes used to locate the target are elected by the cluster head. It sends a Target Detection message to them. Subsequently, it waits for the Targeted packet.

The cluster head will wait for Target Detection messages. After receiving three Target Detection messages, localizing the target is done by the cluster head. Then the cluster head sends a Target Info message to the sink and its neighbourhood cluster heads. These cluster head create a detection wall in the border of the sender cell and creates secondary clusters in that part of the border. Some border nodes will be elected as the cluster head and the others will join the nearest cluster heads. This is done by a Ready to Detection message that the cluster head sends.

4. Simulation and results

We used ns2 for evaluating our simulations in TTBVG protocol. The simulation conditions are listed in table 1. We compared TTBVG (proposed protocol) with DPT and EDPT. The difference between the scenarios is in the target speeds, then increased the target speed and evaluated its influence on the efficiency of algorithms.

4.1. Residual energy

The residual energy of the nodes was evaluated and the results obtained were shown in figures 5 and 6. These results prove the efficiency of TTBVG. As shown in figures 5 and 6, the life time is increased and energy consumptions of the nodes decreased.

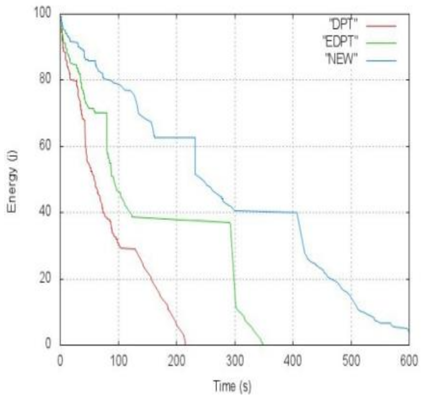

Figure 5. Residual energy of nodes when target speed is 5m/s.

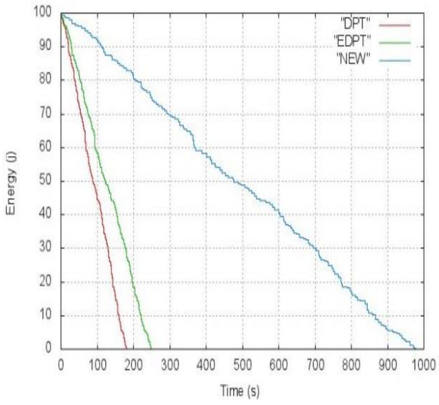

Figure 6. Residual energy of nodes when target speed is 1m/s.

4.2. Error rate

The error rate was calculated. TTBVG locates the target position more correctly. In figure 7, the error rates of DPT, EDPT, and TTBVG are shown with respect to different speeds of the target. The results obtained show the excellence of TTBVG.

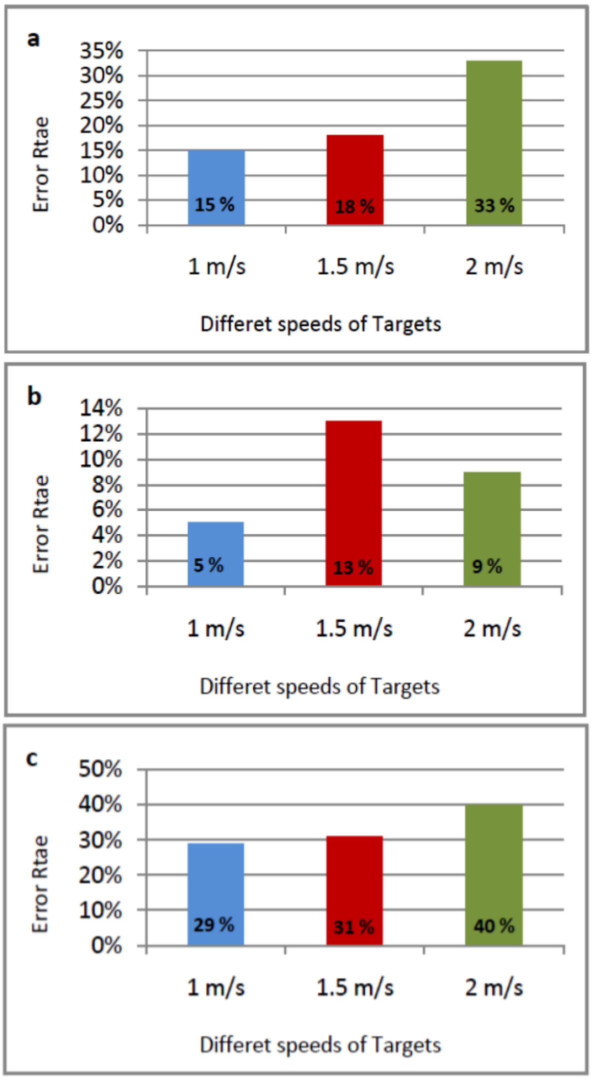

Figure 7. Error rate with respect to different speeds of target. a) DPT, b) EDPT, and c) (TTBVG) proposed protocol.

5. Conclusion and future works

Target tracking is one of the new network paradigms and important applications of WSNs. However, tracking a moving target in cluster-based WSNs suffers from the boundary problem. In this paper, in order to resolve this problem in cluster-based WSNs, a new mobility management protocol namely Target Tracking Based on Virtual Grid (TTBVG) was suggested. This protocol converts the on-demand dynamic clusters to scalable cluster-based WSNs using boundary nodes, and facilitates sensors' collaboration around clusters. In this manner, each sensor node has the probability of becoming a cluster head and apperceives the trade-off between energy consumption and local sensor collaboration in cluster-based sensor networks. The simulation results of this work demonstrated the efficiency of TTBVG in both the one-hop and multi-hop cluster-based sensor networks. TTBVG is very useful for the research groups that are interested in the development, modification or optimization of tracking algorithms for WSNs. For the future works, the proposed protocol can be of use for other applications in WSN such as emergency preparedness and habitat monitoring.

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نشریه هوش مصنوعی و داده کاوی

ردیابی هدف مبتنی بر شبکه مجازی در شبکه‌های حسگر بی‌سیم

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چکیده:

یکی از کاربردهای مهم و معمولِ شبکه‌های حسگر بی‌سیم ردیابی هدف است. اگرچه ردیابی هدف منافعی را برای شبکه های حسگر بی‌سیم در مقیاس بزرگ فراهم می‌آورد و آنها را به شکل خوشه‌ها سازمان‌دهی می‌کند، با این حال ردیابی یک هدف متحرک در شبکه حسگر بی‌سیم مبتنی بر خوشه از مشکلات مرزی رنج می‌برد. هدف اصلی از این مقاله معرفی یک پروتکل مدیریت متحرکِ موثر و کارآمد، با نام ردیابی هدف مبتنی بر شبکه مجازی است، که برای ردیابی هدف، خوشه‌بندیِ پویایِ مبتنی بر تقاضا را با خوشه‌بندی شبکه‌های حسگر بی‌سیم ادغام می‌کند. این پروتکل با استفاده از گره های مرزی و با همکاری سنسور های اطراف خوشه‌ها، خوشه‌بندیِ پویایِ مبتنی بر تقاضا را به یک شبکه حسگر بی‌سیمِ مبتنی بر خوشه و مقیاس‌پذیر تبدیل می‌کند. در این روش، هر گره حسگر با احتمال تبدیل شدن به سرخوشه، یک نرخ تعادلی بین مصرف انرژی و همکاری سنسور محلی در شبکه های حسگر مبتنی بر خوشه ایجاد می‌کند. نتایج شبیه‌سازی از این کار بهره‌وریِ پروتکل ارائه شده را در هر دو روش تک-گامه و چندگامه در شبکه‌های حسگر بی‌سیمِ مبتنی بر خوشه نشان می‌دهد.

کلمات کلیدی: ردیابی هدف، شبکه مجازی، خوشه‌بندی، شبکه‌های حسگر بی‌سیم، خوشه‌بندی پویا.