A survey on target tracking in well-deployed wireless sensor networks

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***Abstract*— This paper presents a general view of the target tracking in Wireless Sensor Networks (WSN) with proper deployment of it. Target tracking task in WSN can be more accurately and efficiently accomplished, given the circumstance where the WSN is more proper deployed, for example, the coverage with clearer border and less holes, sensors with less movement, and connectivity well preserved. To prove this thought, several protocols of target tracking and various aspects of deployment in WSN are investigated.**

***Index Terms*— target tracking, deployment, Wireless Sensor Networks (WSN)**

I. Introduction

TARGET tracking is known to be one of the core applications in battlefield monitoring. In recent years, research on target tracking in wireless sensor networks (WSN) becomes more and more popular. Since deployment of WSN has its own intrinsic characteristics, like coverage, connectivity, energy consumption, etc., tracking task stands a great difference from traditional one. If we want to perform target tracking in WSN, two main issues should be considered. First, the deployment of the WSN must be appropriate. To be more specific, the coverage and the connectivity problem are of twofold concern. The more proper the coverage is, the more accurately the targets would be localized and tracked. Second, target tracking has its own characteristic, such as trajectory estimation and data association. But when the problem comes into WSN environment, meanwhile tracking targets gains additional aspects to be dealt with, for example, the sensors' self-adaption or redeployment for tracking mobile targets. For the purpose of tracking targets, sensors can be static or mobile. If they are static, the problem is mainly about tracking scheme and task scheduling of sensors; otherwise, when they are mobile, the problem may come to be WSN redeployment and maximum coverage achievement.

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Sensor deployment can be classified by: (1) static and mobile, (2) 2-dimention and 3-dimention, (3) coverage and connectivity, (4) dense and sparse, (5) deterministic and random, (6) homogeneous and heterogeneous sensors. Coverage methods have three categories: full/blanket coverage, barrier coverage and target coverage. Our aim is to achieve a better coverage of WSN, and by saying "better", we mean a higher coverage ratio, a clearer border of the region and less holes.

As we focus on the target tracking in WSN, wireless mobile sensor network deployment, coverage problem and the protocols of target tracking in WSN will be mainly discussed. Other related issues including connectivity, work scheduling, energy efficiency, fault tolerance, etc., will also be mentioned when necessary.

In [1], the general process of tracking targets in WSN can be described as follows: the sensor nodes which can sense the target are in active mode while the remaining are put to be inactive in order to save energy until the target approaches them [2]–[6]. To monitor a mobile target, a group of sensors must be turned active before target reaches to them. This group of active sensors varies along with the velocity of target [7] and schedules from cluster head [5], [6], [8], [9]. [10] gives us a well-categorized statement, but relatively less comparison about the advantages and disadvantages which will be reinforced in this survey. Deployment issues about various aspects are laid by [11]–[13] and [14] and further discussed in this paper.

The rest of the paper is organized as follows. In section II, we describe the classification of target tracking protocols in WSN. Section III reviews the methods of WSN deployment. Conclusion is drawn in section IV in which we bring up future work as well.

II. Classfication of target tracking protocols in WSN

Although target tracking under WSN environment shares some similarities with traditional methods, we must consider its speciality since sensor nodes have limited power and computational capability which may not be

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ample for the complex signal processing algorithm in traditional target tracking. Three typical schemes of hierarchical categories are first detailed: tree-based tracking, cluster-based tracking, prediction-based tracking.

A. Tree-based tracking

[15] gives a publish-and-subscribe tracking method, called Scalable Tracking Using Networked Sensors(STUN), that scales well to large numbers of sensors and moving objects by using hierarchy. The method for building efficient tracking hierarchies, called drain-and-balance (DAB), is well performed on 1D and 2D sensor network topologies. The author argues that STUN gains advantages over traffic-oblivious schemes when the mobility patterns exhibit locality and DAB method can also be useful in large-scale sensor tracking systems. [16] extends the location part of [15], and further brings up a network aggregation model by organizing sensor nodes in logical tree, which reduces the total communication cost. [17] uses a heuristic object tracking algorithm that formulates the problem as 0/1 integer programming. Langarian Relaxation (LR) based approach minimizes the total communication cost of object tracking tree, say, improving about 9.9% energy consumption compared with shortest path tree (SPT), but is less scalable than the above two approaches. [18] provides self organizing and routing capabilities with low computation overhead on sensor nodes and its efficiency and easy maintenance by refilling new nodes to the tracking area when too many nodes have exhausted their energy make it possible to dynamically build up a new network. OCO performs better than the typical cluster-based method LEACH in various scenarios, but suffers a problem that the border nodes must be on all the time, resulting rapid depletion of the nodes' energy.

B. Cluster-based tracking

In [19], Low-Energy Adaptive Clustering Hierarchy (LEACH) has been proposed. LEACH consists of two phases. Firstly, in the set-up phase, sensors may elect a local cluster head randomly among themselves, so that the network may balance energy dissipation across the whole network. After the heads are selected, they advertise to all sensor nodes that they are the new cluster heads. Once the nodes receive the advertisements, each of them decides to which head it would belong. Secondly, in the steady phase, sensors sense and transmit data to the sink through their cluster heads. After a certain period of time the network restarts the set-up phase again. LEACH adopts multi hops to communicate, which makes it more realistic than Direct Communication (DC) method. However, LEACH is a mechanism that one-level clusters are formed by sensors which volunteer to become the CHs, so it exposes twofold sufferings: 1) all the elected CHs may not be close enough to the target and 2) clusters are not formed uniformly such that a CH may not recruit sufficient sensors, because of which it cannot be directly applied into target tracking systems. Besides, its assumption that all nodes have enough power to communicate directly with the base station makes it difficult to apply in a large-scale network. [20] uses the LEACH to organize nodes into static clusters. Since tracking a moving target in cluster-based WSNs suffers the boundary problem when the target moves across or along the boundaries of clusters, this paper provides hybrid cluster-based target tracking (HCTT) protocol which integrates on-demand dynamic clustering into scalable cluster-based WSNs with the help of boundary nodes, thus solving the boundary problem of cluster-based sensor networks and achieving a well tradeoff between energy consumption and local node collaboration.

[21] raises the tier up to two, the higher one constructing a grid structure by a source sensor which detects the target in order to disseminate the tracking information throughout the entire system, while the lower one retrieving the tracking information from the nearest grid point of the local grid by a mobile sink. TTDD model is especially well-suited for the case of multiple mobile sinks. [22] uses Voronoi Diagrams to realize a decentralized, light-weight, dynamic clustering algorithm for single target tracking. The hierarchy envisioned consists of 1) a static backbone of sparsely placed high-capability sensors which will assume the role of a cluster head (CH) upon triggered by certain signal events and 2) moderately to densely populated low-end sensors whose function is to provide sensor information to CHs upon request. The main contribution lays on eliminating contention among sensors and offering more accurate estimates of target locations as a result of better quality data collected and less collision incurred. It shares the similarity with TTDD of dynamically constructing grids/clusters in response to tracking targets, but differs in that the grid structure laid in TTDD is not for the purpose of collecting sensor information and thus does not consider issues 1) when the active CH solicits for sensor information, instead of having all the sensors in its vicinity reply, only a sufficient number of sensors respond with non-redundant information, and 2) both the packets that sensors send to their CHs and packets that CHs report to subscribers do not incur significant collision.

C. Prediction-based tracking

Like cluster-based methods being related to the tree-based methods, prediction-based methods are built upon the tree-based and the cluster-based methods, added with prediction models. [23] presents the Prediction-based Energy Saving scheme (PES) to use simple models to predict a specific location without considering the detailed moving probabilities and focuses on reduction of energy consumption network by keeping most of the nodes in sleeping mode until waken up by an active node. The next location of mobile object is calculated at both sensor nodes and sink from historical data. Kinematics-based prediction, which describes the motion of objects without considering the circumstances that cause the motion, is used as the target prediction methods like most of other works, while dynamics-based prediction studies the relationship between the object motion and its causes. Unlike the physics-based prediction work [23], in [24], target prediction of Probability-Based Prediction and Sleep Scheduling protocol (PPSS) provides a directional probability as the foundation of differentiated sleep scheduling in a geographical area. Then, based on the prediction results, PPSS enhances energy efficiency by reducing the number of proactively awakened nodes and controlling their active time in an integrated manner. When nodes operate in a duty cycling mode, tracking performance can be improved if the target motion can be predicted and nodes along the trajectory can be proactively awakened. PPSS adopts kinematics like [23], and probability as well. By effectively limiting the scope of this local active environment, PPSS improves the energy efficiency with an acceptable loss on the tracking performance. In addition, the design of PPSS protocol shows that it is possible to precisely sleep-schedule nodes without involving much physics. PPSS limitations include not using optimization methods and not covering special cases such as the target movement with abrupt direction changes by the prediction method of PPSS.

D. Peer-to-peer WSN

Different from the hierarchical protocols, the peer-to-peer (P2P) WSN for target tracking comes into sight. In the previous hierarchical methods, for example, the tree or cluster-based methods, the root nodes or the CHs have been laid on heavy computational burden which makes those methods lack of robustness. Peer-to-peer WSN can perform well without the limitation mentioned above by guaranteeing sensors to obtain the desired estimates and relying only on single hop communications between neighboring nodes.

[25] proposes distributed Kalman filtering (DKF) algorithms which consist of a network of micro-Kalman filters each embedded with a high-gain high-pass consensus filter (or consensus protocol). The role of consensus filters is to estimate of global information contribution using only local and neighboring information. The main idea is to use dynamic consensus strategy to the information form sigma-point Kalman filter (ISPKF) that derived from weighted statistical linearization perspective. Each node estimates the global average information contribution by using local and neighbours information rather than by the information from all nodes in the network.

[26] gives a precise example for this type of protocol by bringing up a distributed P2P signal processing framework and introducing a combined target tracking system. In the distributed P2P framework, signal processing is progressively carried out in a set of selected wireless sensor nodes with an integrated criterion based on some feasible factors for achieving the tradeoff between energy consumption and information utility. The combined target tracking system consists of a series of specific in-node algorithms, such as background subtraction based target detection, 2-D integer lifting wavelet transform (ILWT) and support vector machine (SVM) based target classification, auto regressive moving average (ARMA) model based target tracking, and a multi-view localization algorithm based on the distributed P2P signal processing framework. The distributed P2P framework is an effective signal processing framework with better performance in processing, time delay and energy consumption of wireless sensor networks than centralized client/server framework and distributed client/server framework, and the proposed target tracking system based on the distributed P2P signal processing framework can be successfully achieved in strictly constrained wireless sensor networks and perform target detection, classification, tracking and localization.

E. Summary of the protocols

Now, we can draw a summary among the protocols mentioned above. Detailed information is showed in Table I.

III. Deployment in WSN

As we mentioned above, to achieve a more accurate tracking performance, we had better make a more proper deployment of WSN. In [27], deployment patterns with proven optimality that achieve both coverage and connectivity in three dimensional networks are provided. As we concern the target tracking application in WSN, the coverage problem out of deployment problem is mainly put our eye on, without regard of 2D or 3D. [11] gives two taxonomies of deployment in WSN, while [14] argues that a good deployment approach will augment the degree of resource allocation in the network and enable a better performance on information gathering and communication. And existing approaches dealing with sensor deployment can be generally classified into two types: Physics-based and Geometric based [28]. In physics based approach the sensor nodes are assumed as points subject to attractive or repulsive forces like Newtons Law of forces while in Computational geometry based approach the sensor nodes are assumed as points.

A. Dense or sparse deployment into consideration

In most of the work studying coverage it is assumed that the sensor nodes are static, they stay in the same place once they are deployed. Newer sensor nodes have the ability to relocate after they are deployed, these are known as mobile nodes.

The algorithm in [29] has each sensor node determining the location it needs to move to in order to provide maximum coverage. The key weakness in this algorithm is that each node must be within the sensing range of another node in order to determine the optimal location it needs to move to, if a node is not seen by any other nodes then that node cannot determine its relative location. The method introduced in [30] aims to maximize coverage while minimizing sensor movement. The simulations run by the authors show the method does achieve excellent

TABLE I.
CLASSIFICATION OF TARGET TRACKING PROTOCOLS

Tracking protocols	Tree-based	Cluster-based	Prediction-based	Peer-to-Peer WSN	Scheduling	Query	Aggregation
[15]	✓						
[16]	✓					✓	✓
[17]	✓						
[18]	✓						
[19]		✓					
[20]		✓					
[21]		✓				✓	✓
[22]		✓			✓	✓	
[23]			✓				
[24]		✓	✓		✓		✓
[25]				✓			
[26]				✓	✓		

coverage with low amounts of movement but it does require a complex algorithm be run which may tax the sensor nodes. The authors in [31] design three separate deployment protocols that provide a high level of coverage with minimal movement in a short time. The simulations show that the protocols hold up with a limited amount of sensors but there are questions about how scalable the protocols are with larger numbers of sensors.

B. Deterministic or random deployment into consideration

It is easier to develop a coverage scheme for deterministic placement of sensor nodes than for random placement. However in many deployments, it is either impractical or impossible to deploy sensor nodes in a deterministic way.

In [32], the authors propose to arrange the sensors in a diamond pattern which would correspond with a Voronoi polygon. The pattern achieves four way connectivity from each of the nodes with full coverage when the communication range divided by the sensing range is greater than the square root of two. The authors are able to mathematically prove the validity of their pattern, however the pattern is not practical for actual deployment. It assumes that the sensing and communication ranges of every node are a perfect circle as well as the ability to place the sensors in exact locations. Random deployments of sensor nodes are usually dense deployments as well since it is necessary to deploy additional sensors in order to achieve coverage if the sensor nodes are stationary. Networks with mobile sensors usually start out with a random deployment and utilize the mobility property in order to relocate to the optimal location.

C. Virtual Force Based Approach

Virtual force (VF) based approach belongs in the physics-based category. [33] first gives the VF concept following the electromagnetic force in physics. The main idea of it presented is that sensor nodes modeled as points are subjected to attractive or repulsive force according to the distance between each two sensors. The forces are of type Newtons Law. By setting a threshold of desired distances between sensors, each sensor moves according to the summation of the force vectors and eventually a uniform deployment is achieved. VF method helps move sensors from high density area to low density areas, thereby minimizing sensing overlap. Finally, force equilibrium is achieved as a sign of ultimate optimizing state which can further improve the coverage performance of the network.

Potential energy is introduced by [34] in order to determine the functional relationship between the VF and the sensor position. However, the connectivity problem is not well considered and their algorithms also need to hold the global information of the CHs. In [35], each node periodically calculates the virtual force it receives from its neighbors based on the distance with all its neighbors. According to the resulting VF, a node determines the movement speed and direction in the next interval. [36] extends the virtual force algorithm (VFA) to 3D space.

D. Movement Assisted Approach

[37] is a typical example of the movement assisted approach. Mobile sensor network has the capability of movement or locomotion. These movements can be used for placement of sensors and self deployment. Sensor moves in accordance with the direction. The issue of sensor movement is handled in this approach by proposing an algorithm called Scan based movement assisted (S-MART). Besides, SMART takes the communication hole problem into consideration along with controlling moving distance. Another non trivial work [31] also deals with the coverage hole problem.

E. Computational Geometry Based

Computational geometry is to develop efficient algorithm and data structure for solving problem stated in terms of basic geometrical objects: points, lines, segments, polygons, etc. The geometrical structures used are grid and polygons for modeling of sensors. The two common data structure used are Voronoi Diagram (VD) and Delaunay Triangulation (DT). VD mainly decides the sensing range, while its dual diagram, DT focuses the transmission range.

According to [38], it is believed that the Voronoi diagram is a fundamental construct defined by a discrete set of points. In 2D, the Voronoi diagram of a set of discrete sites (points) partitions the plane into a set of convex polygons such that all points inside a polygon are closest to only one site. This construction effectively produces polygons with edges that are equidistant from neighboring sites. The advantage of VD over other geometrical structure, like grid, is that its computational complexity is controlled by one parameter that is the number of sensor in the network.

Among all possible triangulations, the Delaunay triangulation maximizes the smallest angle in each triangle. In addition, a Delaunay triangulation must satisfy the empty circle property, which states that there is a circle containing the end points of a Delaunay edge and no other points (edges). Also, neighborhood information can be extracted from the Delaunay triangulation since sites that are close together are connected. In fact, the Delaunay triangulation can be used to find the two closest sites by considering the shortest edge in the triangulation.

Array based sensor relocation algorithm is proposed in [28] using VD. A local detection diagram (LDD) is introduced as an important tool to detect local coverage holes. Self detection and sensor movement validation schemes are also proposed. [39] uses VD along with VFA scheme for their proposed algorithm to guarantee connectivity and achieve an adaption for obstacles. A coverage optimization algorithm based on particle swarm optimization (PSO) and VD is proposed in [40]. PSO is used to find the optimal deployment of the sensors that gives the best coverage while Voronoi diagram is used to evaluate the fitness of the solution. Their combination makes contribution that the algorithm is fit for the situation where there is a need for a large network in a large region of interest (ROI), while the grid method is used only either when the network is small or when the execution time is not important. Delaunay triangle graph based algorithm (RDTG) is proposed in [41]. RDTG constructs a logical topology graph without intersection of edges, and tries to make nodes neighbor equal to 6 by moving the node according the property of maximize the minimum angle of the triangles in DTG. Delaunay triangle based method is proposed in [42]. The algorithm eliminates the coverage holes near the boundary of sensing area and obstacles. Delaunay triangle is applied for the uncovered regions.

F. Pattern Based Approach

Different patterns are used like grid, triangle, diamond and hexagon for placing the sensors. These patterns are modeled as coverage optimization problem. Tilling and tessellations are also used for deployment modeling. [43] uses grid for uniform distribution of sensor nodes. Popular grid layouts are a unit square, an equilateral triangle, a hexagon, etc. The overall coverage pretty much depends on both the sensing ranges and the deployment scheme of the nodes. K-coverage is the usual way of specifying conditions on coverage. A network is said to have k-coverage if every point in it is covered by at least k sensors. [44] considers both coverage and connectivity and compares the performance of different connectivity (k $\leq$ 6). Three deployment strategies are discussed; uniform random, a square grid, and a pattern-based Tri-Hexagon Tiling (THT) node deployment. In uniform random deployment, each of the sensors has equal probability of being placed at any point inside a given field such that the nodes are scattered on the field. In grid based deployment, each node is placed on each of the grid points. The other strategy is based on tiling. A tiling is the covering of the entire plane with figures which neither overlap nor leave any gaps. Tilings are also sometimes called tesselations. Among different tilings author use a semi-regular tiling where every vertex uses the same set of regular polygons. The above authors' previous work has investigated different deployment models in [45] and proposed a diamond pattern in [46]. [47] which proposes a boolean sensing model is also a representative work of this type.

G. Modeling of Deployment Problem

[48] analogizes WSN and Electrostatics. Deployment of massively dense sensors is discussed with optimal distribution considering issue of network topology. However, this analogy also has important limitations. For example, if the situation moves to a three dimensional topology, adapting the general assumption on the physical and MAC layers accordingly, or they stay in the two dimensional plane but use an alternative assumption, that is more suited to Ultra WideBand communication, the optimal traffic distribution is not in general irrotational, and so can not be interpreted as an electrostatic field. Besides, the analogy can not be extended to include networks that support more than one type of traffic. [35] uses network dynamics for managing mobility. The dynamics of classical mechanics systems are described via underlying laws of motion and laws of force between objects. Based on the network dynamics model, the authors first devise a Parallel and Distributed Network Dynamics (PDND) algorithm that runs on each sensor node to guide its movement. PDND then turns sensor nodes into autonomous entities that are capable of adjusting their locations according to the operational goals and environmental changes.

H. Comparison between existing approaches

A comparison between different approaches is drawn in Table II.

IV. Conclusions

We study some methods of target tracking and provide various taxonomies of deployment in WSN. Thus, the relationship between target tracking means and deployment schemes is revealed. We bring up the idea that in a better deployed WSN, the capability of tracking targets may be elevated. In the future, we would attempt to combine these two territories of research in WSN and discover whether they have more bonds which can be taken advantage of for further improvement in target tracking and deployment in WSN.

TABLE II.
COMPARISON BETWEEN EXISTING APPROACHES

Ref. No.	Algorithm Proposed	Distributed/ Centralized	Dense/ Sparse	Deterministic/ Random	2D/ 3D	Coverage/ Connectivity	Main Issue /Advantage	Main Disadvantage
[27]	regular lattice deployment patterns			Deterministic	3D	Full-Coverage and k-Connectivity (k = 14, 6)	deployment patterns with proven optimality	other connectivity patterns
[29]	newer nodes deployed by the previous information	Centralized	Dense	Deterministic		maximum coverage	ensure that nodes retain line-of-sight relationships with one another	each node must be within the sensing range of another
[30]	VD and Fuzzy logic (FReD)	Distributed	Dense	Random	2D	maximize coverage	minimizing sensor movement	energy efficiency
[31]	VEC (VECtor-based), VOR (VORonoi-based), and Minimax	Distributed			2D	high coverage	calculate the target positions of the sensor	how scalable the protocols are with many sensors
[32]	Diamond pattern & Double-strip pattern			Deterministic	2D	four-connectivity & full coverage	optimal deployment patterns	assumption that sensing and communication ranges are a perfect circle
[33]	VFA & probabilistic target localization algorithm & CH	Distributed		Random	2D	maximize coverage	enhance the coverage after an initial random placement of sensors	no route plan for repositioning the sensors, not continuous
[34]	Potential energy/ Potential field	Distributed			2D	Coverage	functional relationship between the VF and the sensor position	need to hold the global CHs' information
[35]	VFA & PDND	Distributed			2D	Coverage	Mobility for Improving Coverage	
[36]	VFA & central gravitation and equilibrium force	Distributed		Deterministic	3D	Coverage	get better sensor distribution	complex environment with obstacles and multi-objectives
[37]	VFA & SMART	Centralized			2D	Coverage	movement assisted	Obstacle adaptability
[28]	Local Detection Diagram(LDD)	Distributed			2D	Coverage & Connectivity	local coverage hole detection	Obstacle Adaptability, Connectivity
[39]	Virtual Force & Floor based Scheme	Distributed	Sparse	Random	2D	Coverage & Connectivity	maximize sensing coverage and guarantee connectivity	Computational Overhead
[40]	PSO & VD	Centralized	Dense	Random	2D	Coverage	find the optimal coverage of the sensors	Obstacle Adaptability, Connectivity
[41]	VFA & RDTG	Centralized		Random	2D	Coverage & Connectivity	constructs a logical topology graph without intersection of edges	Obstacle Adaptability
[42]	VD & DTG			Random	2D	Coverage	eliminates the coverage holes near the boundary of sensing area and obstacles	
[43]	sensor grid-network	Distributed		Random	2D	Coverage & Connectivity	maintain connectivity with coverage	
[44]	uniform random, a square grid, and a pattern-based Tri-Hexagon Tiling (THT) node deployment			Deterministic	2D	Full Coverage and k-Connectivity ($k \leq 6$)	Optimal Deployment Patterns	other connectivity patterns
[45]	Strip-based Deployment Pattern				2D	Coverage & Connectivity	optimal deployment pattern	
[46]	diamond pattern				2D	Four-Connectivity and Full-Coverage	Optimal Deployment Patterns	
[47]	Boolean sensing model			Random		Coverage	possible structural model choices for an unbounded search region	
[48]	analogize WSN and Electrostatics		Dense		2D	Connectivity	Electrostatic Problem	analogy's limitation

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