Static Clustering for Target Tracking in Wireless Sensor Networks

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Abstract

The aim of this paper is to consider an energy efficient algorithm that uses static clustering architecture in which all nodes are kept in sleep state, except the active cluster is involved in the tracking process. Simulation experiments have been showed that our algorithm is much more efficient and outperforms other well-known tracking algorithms due to lower energy consumption while achieving acceptable tracking accuracy.

Keywords: target tracking, wireless sensor networks, static clustering.

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1. Introduction

A Wireless Sensor Network (WSN) consists of hundreds or thousands of tiny, low cost, low power, and intelligent sensor nodes that have small capacities of sensing, processing and communication deployed over a certain geographical area [1, 5]. Typically, these nodes report sensed data to a base station for further processing and data fusion. Usually, sensors are equipped with small non-rechargeable and irreplaceable batteries.

WSNs have been employed in a large spectrum of applications such as wildlife animal monitoring, military intrusion detection, surveillance disaster management, as well as healthcare systems [6]. On the other hand, mobile target tracking is considered a milestone of all just mentioned applications. The goal is to detect the target entering the monitored area by sensor nodes, estimate its location, report the location information to the base station, as well as track the positions' estimate as the target moves across a certain path [7]. The task of tracking a target in WSNs is a challenging matter due to the following issues: sensors resources limitation, network scalability, data redundancy since adjacent sensor nodes often monitor the same mobile target and may have similar data. In this paper, we propose an algorithm for tracking a mobile target in WSN based on static clustering architecture. The proposed algorithm uses uniform grid deployment of sensors. We aim to achieve high energy efficiency by keeping only one active cluster of nine sensors in the vicinity of the target to participate in tracking process while preserving others in sleep state. Through Matlab simulation, the proposed algorithm achieves much lower energy consumption when compared with two well-known target tracking schemes in literature, namely, Naïve and Randomize while achieving acceptable tracking error.

2. Brief literature review

Recent developments in wireless communication and electronic devices made it possible to fabricate low cost and small sensor devices. These devices have the capability of communicating with each other and a base station up to the end user or the administrator [1, 3]. WSN is a network that is formed when a set of small sensor devices are deployed randomly or manually in a physical environment to cooperate for observation of an event of interest [8, 9]. The sensors in the vicinity of the event of interest should be able to monitor it and report back the observed data to the base station.

Energy is scarcest resource in WSNs that should be utilized properly because it is impossible or inconvenient to recharge the sensor nodes, thus energy efficiency is an important performance metric and directly affects the network lifetime [1, 2, 4].

WSNs are used in military, environmental, civil, and healthcare applications because of its wireless nature [1, 2]. All these applications involve tracking a mobile target scenario where in all of these applications the network sensors assigned the task of continuously detecting, localizing and reporting the positions of the tracked mobile target to the base station while it's moving along a certain path [10]. The target can be for example an animal in wildlife monitored area, changes in environmental phenomenon (light, temperature, pressure, and acoustics) or security attacks in the form of chemical, biological, or radiological weapons [11].

Alternatively, target tracking in course of maintaining the balance between network resources like energy, communication bandwidth, tracking accuracy, and overheads is extremely challenging [12]. Many studies are presented in the literature for designing efficient algorithms for mobile target tracking in WSNs based on various approaches. One of the most efficient approaches is based on clustering architecture.

In static clustering architecture, clusters are formed statically at the time of network deployment. The attributes of each cluster, such as the size of a cluster, the area it covers, the sensor members,

and the cluster head (CH) are static [13]. This means that throughout the network progress, the sensor nodes remain attached to the same pre-assigned CHs [14].

When the target arrives into the cluster area, the CH will be active and activate the other cluster members to keep localizing and tracking the detected target. When the target leaves the cluster vicinity to another, the current CH will activate the new one to keep tracking the target.

3. Proposed algorithm

Our proposed algorithm is based on static clustering architecture where the nodes that can act as CHs during the tracking process are pre-determined in network deployment phase and these nodes are initialized with listen state while keeping others in sleep state to conserve network energy. It is worthy to mention that the network is heterogeneous. In other words, the pre-determined CHs are assigned more energy and computation capabilities than the other nodes in order to increase the tracking performance and network lifetime [15].

In the proposed algorithm, starting with the network deployment phase, two kinds of lists are maintained in each pre-determined CH node: the neighboring CHs list and the candidate cluster members list while one list is maintained on each candidate cluster member node which is the neighboring CHs list.

The active CH that is currently monitoring the target will be elected based on not only just the measured distance from the target, but also it has to be one of the pre-determined CHs. Afterwards, it will invite the surrounding cluster members to join the formed cluster by sending invite messages and the cluster members in turn announce its new active CH for the neighboring CHs. Thus, the cluster members and the surrounding CHs which detect the target will reply with their distance readings to the current active CH within a certain time delay to compute the target estimated location. Besides on this, the current active CH checks to see if it is still the closest to the target; if so, it remains the active CH for the next round and reassigns the same cluster members. Otherwise, a new active CH node will to be elected from the surrounding CHs based on their distance readings. The closest to the target will be elected to be the next active CH. The active CH phase is then started and the current active CH sends a migrate message to the new elected one with the archive data, if available. Thus, the new elected active CH will repeat the operation of cluster members' invitation, target localization and sending the estimated location to the base station node, resulting in continuous tracking of the target.

Fig. 1 shows a general view of our proposed static clustering algorithm simulation model in which the nodes in violet colour are the pre-determined CHs that can act the role of the active CH state in the cluster formed during the tracking process, as mentioned previously. These nodes are chosen because of its centered locations of squares (i.e., the cluster shape) of cluster member nodes and they will not be changed during the network progress. It is obvious from this figure that the current and previous active CH nodes are chosen to be not only the closest to the target, but also they need to be from the pre-determined CHs, as formerly discussed.

The static head scheme overcomes the known drawback of static clustering architecture since cluster member nodes will not have static membership with only one cluster during the tracking process [16], but rather it can be a member of at least two clusters at different times which consequently leads to decreasing state transitions of sensor nodes along the target path. This flexible sensors membership improves the environment adaption for high speed moving target. On the other hand, less number of sensor nodes need to be deployed while the network coverage will not be affected.
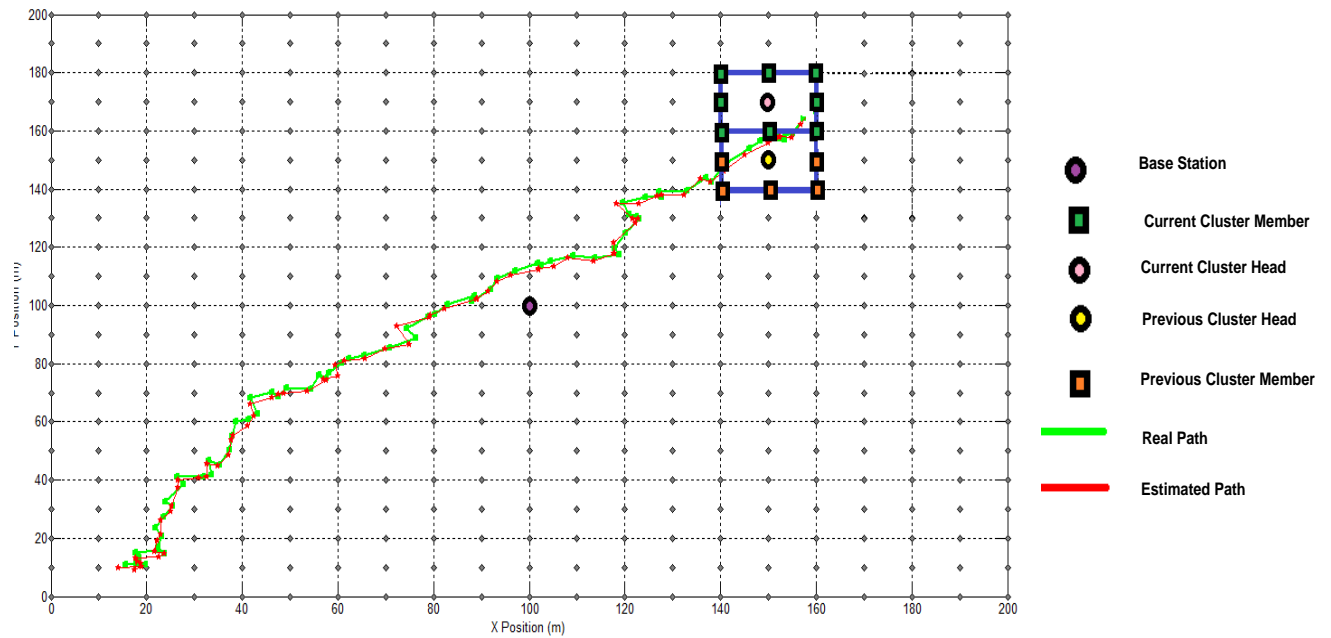
Fig. 1. Proposed algorithm simulation model.

4. Performance evaluation

Simulating the performance of our proposed static clustering algorithm along with the two well-known target tracking approaches has been carried out using Matlab simulation. The sensor radio energy model used in our simulations is the same as the one employed in [17]. In this model, a radio dissipates E_{elec}=50 nJ/bit to run the transmitter or receiver circuitry and ε_{amp} = 100 pJ/bit/m^2 for the transmitter amplifier. The localization algorithm employed is based on the principle of measuring time of arrival (TOA) [13]. Simulation environment has 21× 21 nodes that are uniformly deployed on a grid over a 200×200 meters 2D square sensing area. The distance between any two neighbouring nodes is equal to 10 meters. The base station is located at the middle of the sensing area. The sensing range of each node is the same as transmission range and chosen to be 10×√2 meters. Each node will be referenced by (X, Y) coordinates; 16 bit each. In our simulations, the target path is chosen to be random so that the target's trajectory is not regular. The target path is composed of small line segments. Moreover, target speed is within the range of 0-18 meter/sec.

4.1. Energy Consumption Study

To analyze the proposed algorithm, we compare it against two well-known target tracking approaches, that are, Naïve and Randomize. We first examine the relationship between energy consumption and sensor density. To calculate the sensor density, we used the following equation [18]:

$$Density = \frac{\left(N\pi R^2\right)}{A}$$

(1)

Where N is the number of sensor nodes in each side of the monitored area A that is varied from 21 to 35 node, and R is the radio transmission range. In Naïve, all nodes stay in active state all the time and send the collected data to the base station periodically [19-20]. Therefore, the energy consumption is high as shown in Fig. 2. While in Randomize, each node is in active sate with a probability P. On average, a fraction P of all nodes will be in active state, tracking the target.

Fig. 2 shows energy consumption for Naïve, Randomize, and our proposed algorithm with different values of *P*. It is clear that our proposed algorithm has much less energy consumption than the other schemes for all density values. In addition, the proposed algorithm has a minimal sensitivity against density while this is could not be achieved for the others.
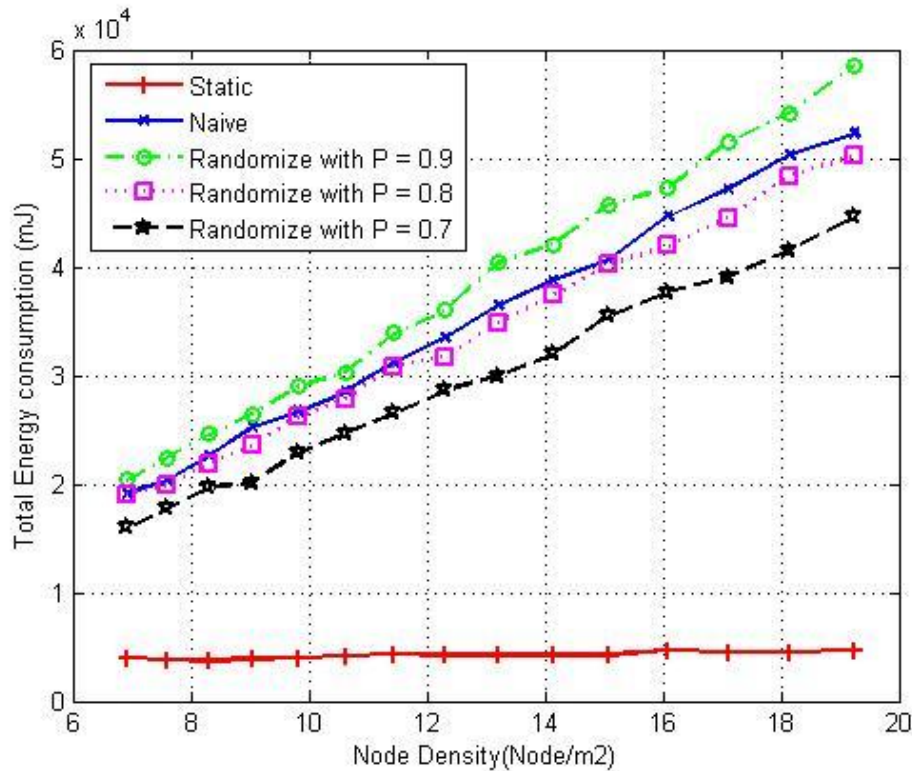

Fig. 2. Energy consumption versus sensor density.

4.2. Tracking Error Study

The other parameter in which we are interested in this paper is the tracking error. Tracking error represents the average tracking error between the real location (X_r, Y_r) and the estimated location (X_e, Y_e) when the target is being tracked for certain time interval *T*. It is calculated using the following equation:

$$\text{Error} = \frac{1}{T} \sum_{T}^{1} \sqrt{(X_r - X_e)^2 + (Y_r - Y_e)^2} \tag{2}$$

As shown in Fig. 3, the minimum error achieved is for Naïve scheme which is due to the involvement of all sensor nodes in the tracking process. Our proposed algorithm achieves acceptable results and outperforms Randomize scheme for multiple values of sensor density bearing in mind the drastic increase of energy consumption of the two schemes when being compared with our proposed algorithm.
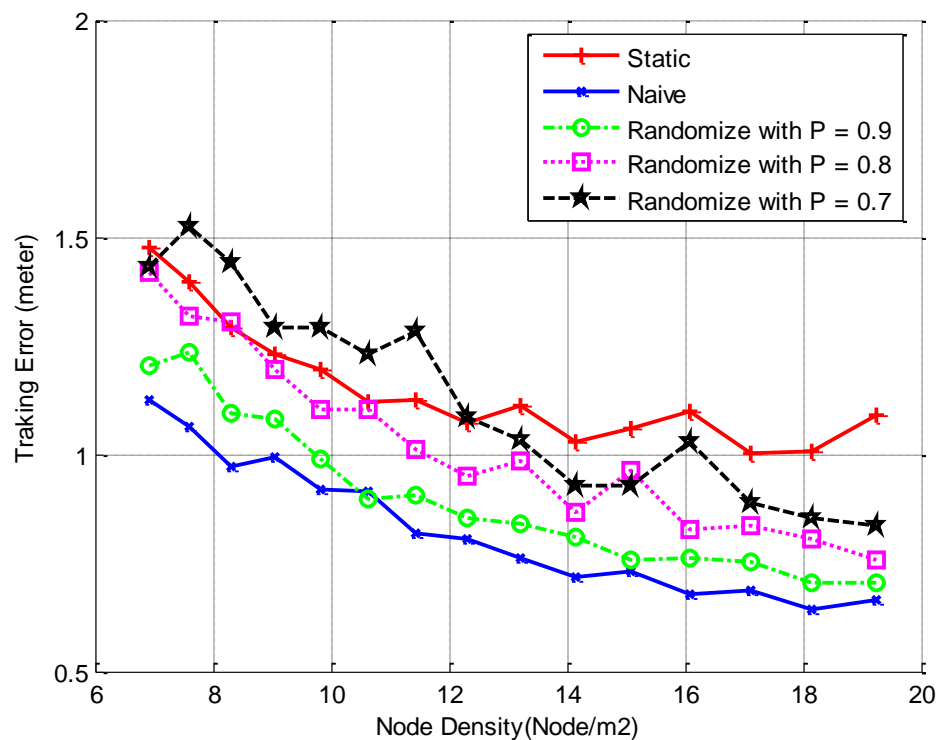
Fig. 3. Tracking error versus sensor density.

5. Conclusions and Future Work

In this paper, we proposed a static clustering algorithm for mobile target tracking in WSN. In our algorithm, the CHs are pre-determined in network deployment where these nodes are initialized with listen state to monitor the target while preserving others in sleep state. The CH nodes are chosen to be powerful nodes with efficient calculation capabilities and more energy than other network sensors because of its high processing tasks during the network progress. This will increase the network life time.

During the tracking process, one cluster of nine sensors; one CH and eight cluster members; is active in the vicinity of the target. This will achieve high energy efficiency while keeping the tracking error low. For future work, other parameters can be considered to study its effect on network performance out of which, target peed, target missing rate, and sensors residual energy on network lifetime. Moreover, the proposed algorithm may be extended to detect and track multiple targets to intend more realistic solutions but we expect the scenario will become more complicated and may be influenced by additional factors.

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